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A Compact, Efficient Lidar Instrument for the Measurement of Ozone Profiles from the SOFIA Upper Deck

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ABSTRACT

The upper deck of the B747 aircraft that houses the Stratospheric Observatory for Infrared Astronomy (SOFIA), provides an excellent platform for a suite of atmospheric chemistry instruments. Of particular importance in any atmospheric dataset, is the measurement of ozone profiles from the troposphere into the stratosphere. We propose that a compact, zenith viewing Differential Absorption Lidar (DIAL) would be an extremely important instrument for an Earth Science Instrument Suite on the upper deck of the Sophia B747 aircraft.

INTRODUCTION

Ozone chemistry occupies an important position in any discussion of atmospheric chemistry. It has long been known that ozone in the stratosphere protects the surface of the earth from harmful UV radiation. And it has also been demonstrated, after a large amount of both experimental and theoretical research, that the stratospheric ozone layer is fragile and has been depleted due to the recent injection of chloro-fluorocarbons into the atmosphere. Much of the research in atmospheric science has been directed at understanding and quantifying the effects of CFC's on ozone, and the anticipated slow recovery. Indeed most of the atmospheric chemistry satellite payloads launched in the last 20 years or so have had an ozone sensor on board.

As part of this effort to understand stratospheric ozone chemistry, NASA has flown Differential Absorption Lidar instruments to measure the vertical profile of ozone in the stratosphere. There have been two such DIAL instruments flown on board the NASA DC-8: the first, built by the Lidar Applications Group at NASA LaRC, and more recently, an ozone and temperature lidar, built by the Atmospheric Chemistry and Dynamics Branch at NASA GSFC. The Langley instrument uses a pair of Nd-YAG-pumped, doubled dye lasers to generate the pair of transmitted wavelengths, while the Goddard instrument uses an excimer laser and the third harmonic of a Nd-YAG laser to generate the two DIAL wavelengths. While both of these instruments have made high quality measurements (see Figure1 for an example of ozone DIAL measurements from the DC-8), the main point here is that both of these instruments make use of standard laboratory lasers and, as a result, are quite large. They are clearly not suitable for a new platform with limited space.

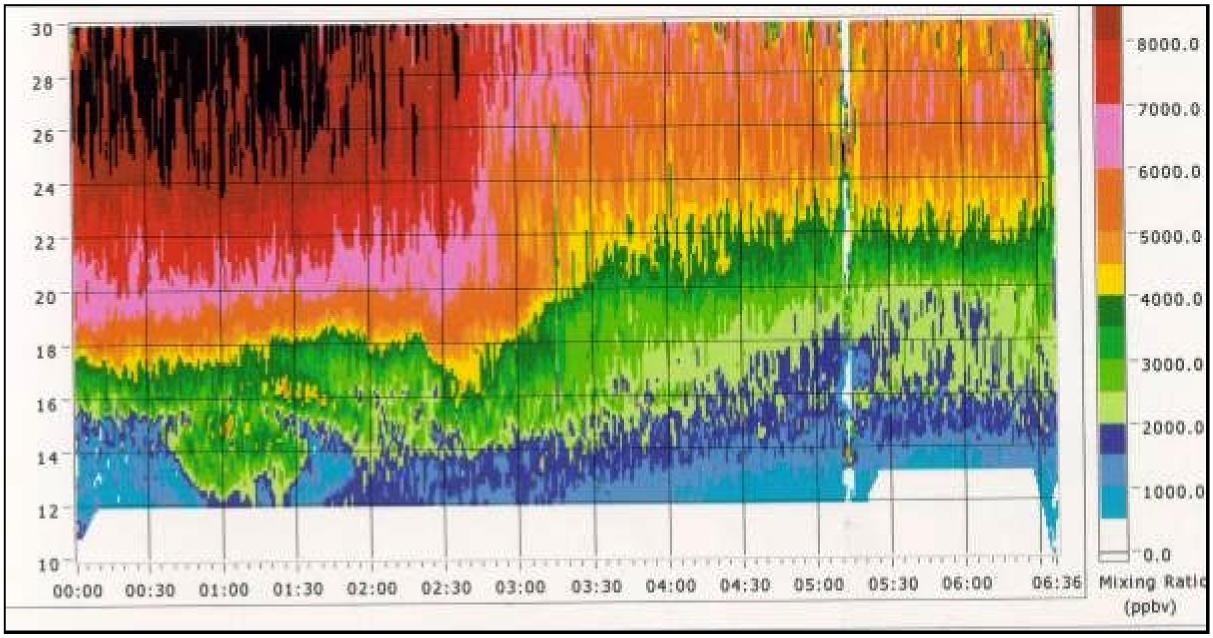

Fig. 1: An ozone curtain file obtained by the NASA GSFC AROTAL Lidar. This plot shows a segment of a transit flight from Edwards AFB to Kiruna, Sweden. Note the lower ozone as the aircraft enters the polar vortex.

LIGHTWEIGHT LIDAR

Because of the importance of understanding ozone chemistry in the stratosphere and the troposphere, and understanding the exchange at the troposphere-stratosphere boundary, many of the new satellite instruments will be designed to make measurements in this region and also farther down into the troposphere. The validation of these new satellite sensors is critical to the credibility of the data retrieved from them. The airborne lidar instruments mentioned above have been involved in SAGE III and POAM validation and have contributed significantly to the confidence placed in the results from those instruments. Such intercomparison of aircraft and ground-based data with satellite instruments, is necessarily an ongoing enterprise to avoid errors due to onboard instrument changes. An upward looking, small, efficient, and lightweight DIAL lidar for stratospheric ozone profile measurements is likely the most important instrument that could be placed on the SOPHIA aircraft for atmospheric chemical and dynamical studies. Ozone is widely used as a tracer gas for studying the dynamics of the stratosphere, and for strat-trop exchange.

Recent laser technological developments have made a small, lightweight lidar feasible. The advent of diode-pumped lasers (completely solid state) has greatly reduced the size of a Nd-YAG laser, and, at the same time, greatly increased its' reliability. ITT has been developing the technical expertise to build high-powered UV modules based on mixing the output from an Optical Parametric Oscillator mixed with the third harmonic of a Nd-YAG laser. This development has been part of the NASA Laser Risk Reduction Program for Space-based laser, but some of this technology is now available and suitable for aircraft use.

ITT has demonstrated their high-powered UV modules to be 15% efficient from the Nd-YAG fundamental to the ozone wavelengths, when the YAG laser has the appropriate beam characteristics. They have also demonstrated > 50Watts of Nd-YAG fundamental in a single longitudinal mode, 1-kHz laser suitable for pumping the UV modules. This translates into a 7.5 W UV source for each of the DIAL wavelengths. (For comparison, the dye laser based lidar from Langley Research Center, which has been very successful, delivers less than 1 W in each wavelength.) This laser, as powerful as it is, will have a physical footprint on the order of 1 sq.ft. This is ideal for the lidar instrument proposed.

What I would also propose, but which hasn't been mentioned on the SOFIA website, is that a second, nadir-viewing lidar, operating at wavelengths slightly shorter than the stratospheric lidar, be mounted in the cargo hold of the 747. This would dramatically increase the capability of the aircraft for atmospheric studies, by enabling continuous tropospheric measurements of ozone. Ozone chemistry in the troposphere is far more complex than in the stratosphere, with many point sources. This would be an extremely valuable instrument for pollution studies, and especially the study of pollution transport. Many would argue that if only one lidar could be placed on board that the nadir-viewing lidar would be the more important.

The technology very briefly outlined above is suitable for both sets of laser wavelengths. Because of the Laser Risk Reduction Program, the cost to build such powerful laser transmitters for lidar instruments is dramatically lower than it was only a year ago. High efficiency receivers can also be made to be compact (but would still require a 14" – 16" aperture). Advances in electronics have made data acquisition systems smaller as well. Technology has advanced in all areas of lidar instrumentation to provide the same or more capability in ever decreasing package sizes.

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